d. Energy Requirements. The main uses of energy in an electrostatic precipitator are the fan horsepower to move the flue gas through the unit and the power required to maintain the electrostatic field. These two power usages are approximately equal. A typical electrostatic precipitator on a 30,000-lb/hr boiler would require about two to three brake horsepower in fan power consumption and two to three kilowatts to maintain the electrostatic field. The rappers and dust removal systems are other sources of power consumption.

e. Application of Electrostatic Precipitators. Electrostatic precipitators can be designed to function efficiently on almost any boiler, either for a new or retrofit installation, if sufficient physical space exists. However, it is important to have a good knowledge of the fuel analysis which will actually be burned, since this has a major effect upon the design of the precipitator. Once the precipitator has been designed and sized for a given fuel, major inefficiencies and operating problems can result from fuel changes.

2-35. WET SCRUBBERS.

A wet scrubber is a device designed to use a liquid to separate particulate contaminants from a flue gas stream. Although they are rarely used on Army boilers, they have some potential application and advantages over other types of particulate control devices and are thus discussed briefly in this manual. More details can be found in Army Manual TM 5-815. Most wet scrubber applications to Army boilers would be of the wet approach venturi type (figure 2-103). It is very compact and has the capability to collect particles down to submicron size with about 99 percent efficiency, or even more if necessary. Its principle of operation is somewhat similar to a mechanical collector, but it adds the action of liquid scrubbing to the centrifugal and inertial forces. The incoming gas steam accelerates and atomizes the liquid droplets. These atomized droplets then wash the dust out of the gas steam in the same manner that a severe rainstorm can wash dust out of the atmosphere. Pressure drop through a wet scrubber increses with decreasing particle size and increasing collection efficiency. For a venturi scruber applied to a coal-fired boiler, pressure dropo typically ranges from 20 to 25 in-H_2O. This creates a significant penalty in fan horsepower requirements and is one of the primary reasons that wet scrubbers are seldom applied to Army boilers. Other types of scrubbers can lower this horsepower requirement, but their collection efficiencies are also lowr. The other major disadvantage of the wet scrubber is its water usage. The cost of pretreating the water and the cost and complexity of treating the wste slurry from the scrubber discharge can be significant. The primary advantages of a wet scrubber are its compact size and its tolerance for extremely high gas temperatures. These two characteristics make it potentially useful for retrofit application where other types of control devices might not be applicable due to efficiency or space requirements.

SECTION VI. AUXILIARY EQUIPMENT

2-36. FEEDWATER HEATERS.

Closed feedwater heaters of the tube and shell type are used to preheat feedwater going to deaerators and hot water boilers as well as for deaerating heating. These closed feedwater heaters can make use of turbine exhaust steam or waste heat generated in the boiler plant to improve overall plant efficiency. Deaerators, deaerating heaters, surge tanks, and condensate return tanks are discussed in chapter 4. Figure 2-104 illustrates a closed tube and shell heat exhanged used for feedwater heating.

2-37. PUMPS AND INJECTORS.

The selection and replacement of pumps require consideration of capacity and pressure requirements, the type and temperature of fluid to be handled, and the type of pump best suited for the job requirements. Performance characteristics vary widely, even among pumps of the same type and capacity. Pumps can be classified into four groups: centrifugal pumps, reciprocating piston pumps, rotary positive displacement pumps, and jet pumps/injectors. The characteristics of these groups are discussed later.

a. Installation. The selection of a pump for a particular job involves many considerations, but once the pump is selected, successful performance depends upon details of the installation. This is particularly true where the pump must lift the fluid or when the fluid is heated. Greater care must be exercised in design and installation of the suction line than of the pump discharge. A strainer is required to prevent foreign objects from entering and clogging the pump or piping. The maximum suction lift or minimum suction lift or minimum suction head depends to a great extent upon the temperature of the water and the distance of the pump above sea level as noted in table 2-7. The following rules should be observed when installing a suction line to a pump. Disregarding any of the following rules may ead to unsatisfactory operation or complete failure:

(1) The line must be tight. A leak in the discharge line may be annoying, but a leak in the suction line may

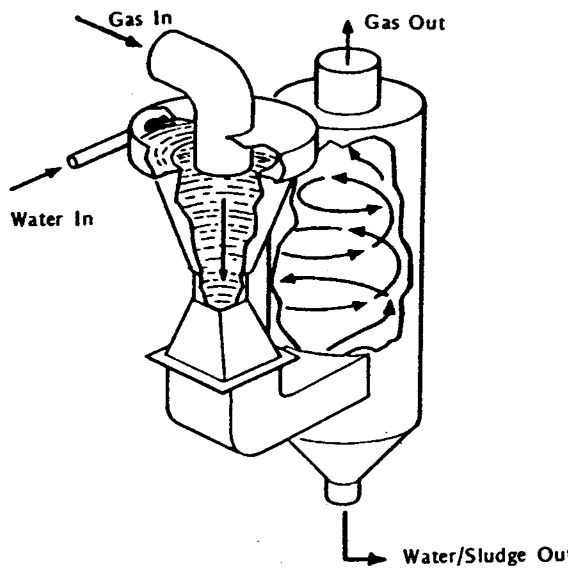

FIGURE 2-103. WET APPROACH VENTURI SCRUBBER

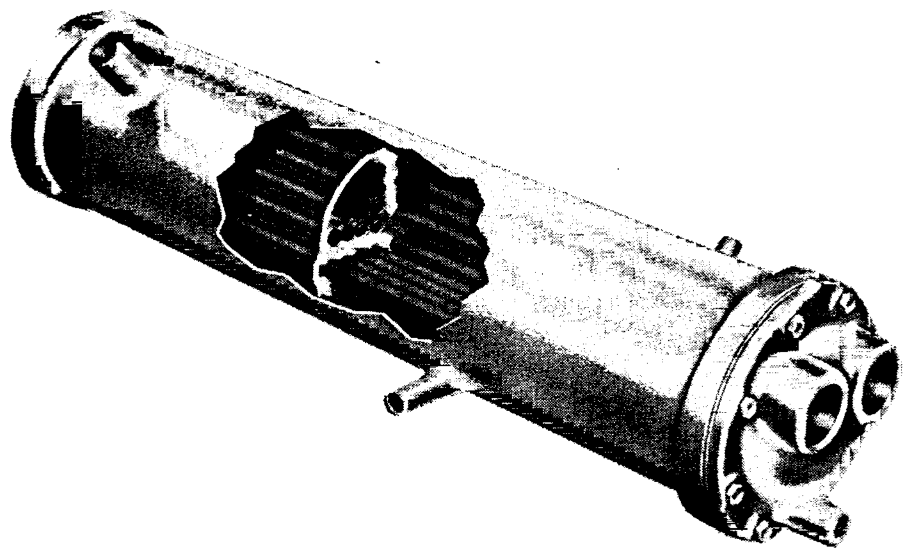

FIGURE 2-104. TUBE AND SHELL HEAT EXCHANGER

lead to inoperation of the pump.

(2) Keep the suction lift, or the vertical distance from the pump to the water supply, as small as possible.

(3) Keep the suction line as short as possible. Keep the number of fittings, such as ells, tees, reducers, and valves to a minimum.

(4) To reduce the losses caused by the pipe friction and high velocity, keep the diameter of the suction line as large as practical.

(5) To prevent formation of air pockets, maintain proper slope on horizontal sections of pipe. Slope the line away from the pump for a suction lift and toward the pump for a suction head. (Reference figure 2-105A). (6) Do not use fittings which permit the formation of air pockets. (reference figure 2-105B). Note: An air chamber is occasionally used on the suction line of a pump to smooth out pressure fluctuations or surges. These must be carefully designed and installed to ensure proper operation.

(7) To keep the line and pump full of water when the pump is idle, install a foot valve on the inlet end of a suction line. A foot valve is a special type of check valve made for this purpose. Very little force is required to operate it, and a strainer is usually incorporated. A foot valve has no value when the pump is located below the source of water supply.

(8) Properly guard all gears, belts, shafts, and other moving parts exposed to hazardous contact, and provide drains from all pump bases.

TABLE 2-7.
PERMISSIBLE MAXIMUM SUCTION LIFTS AND MINIMUM SUCTION HEADS IN FEET FOR VARIOUS TEMPERATURS AND ALTITUDES

	Water Temperature (F)								
Altitude	60	80	100	120	140	160	180	200	210
At sea level	-22	-17	-13	-8	-4	+0	+5	+10	+12
2,000′ above	-19	-15	-11	-6	-2	+3	+7	+12	+15
6,000′ above	-15	-11	-6	-2	+3	+7	+12	+16	—
10,000′ above	-11	-7	-2	+2	+7	+11	+16	—	—

NOTE: (-) indicates maximum suction lift, or distance of pump above water.
(+) indicates suction head, or distance of pump below water.

b. Centrifugal Pumps. Centrifugal pumps use a rotating impeller to give velocity and pressure to the fluid. This type of pupmp is widely used in boiler feed and condensate pumping applications. Figure 2-106 illustrates a horizontal split case type of centrifugal pump. Centrifugal pumps are available in many configurations, including single and double suction, single and double volute, multistage, and vertical. Although these pumps look different, they all have basically the same components and operate similarly. They are compact, of simple construction, discharge at a uniform rate of flow and prssure, contain no valves or pistons, operate at a high speed, and can handle dirty water. They have two major disadvantages: comparatively low efficiency, and inability to discharge air or vapor. However, their advantages more than offset the lower efficiency. The inability to discharge air can be overcome by proper installation and operating practices.

(1) **Construction.** The pump shown in figure 2-106 consists of the rotating element called an impeller, the casing, the shaft, and the parts used for sealing the pump against leakage.

(a) The impeller consists of two disks separated by a number of vanes which form passages for the water and are connected to the hub. This impeller may be of cast iron, bronze, steel, or other alloys, depending upon the fluid to be handled. Its diameter depends on its operating speed and the difference between suction and discharge pressures. The pressure difference is usually called the pump head and is measured in feet. An impeller may be either single or double suction. The one shown is the double suction type, in which water enters from both sides.

(b) The casing is split on the horizontal center line and contains the inlet and outlet passages. Inlet and outlet connections are usually in the bottom half of the casing, permitting disassembly and repair of the pump without disturbing pipe connections or pump alighment. THe casing guides the water from the inlet connection to th impeller and from the impeller to the discharge connection. The casing, although usually made of cast iron, can be made of other materials if necessary to handle special fluids.

(c) The shaft supports and drives the impeller and is, in turn, supported by the bearings. Babbit-type bearings are used in the pump shown in figure 2-106, though many pumps use ball bearings.

(d) The impeller is held firmly by shaft sleexes which also help to seal against leakage of air into the pump. Sleeves are held in place by two nuts, one of which has a right-hand thread and the other a left-hand thread. Packing is sometimes provided between these nuts and the sleeves to ensure a tight seal. Stuffing boxes are provided where the shaft passes through the casing. Stuffing boxes are filled with packing held in place by packing glands. A brass or bronze lantern ring is often inserted between two adjacent rings of packing to provide a channel for the sealilng water. The sealing water lubricates and cools the packing and shaft sleeve and helps seal against air leakage into the pump. It may be supplied directly from the pump, as show, or from an outside source. The casing has renewable rings to reduce leakage from the discharge to the inlet side of the impeller. Renewable wear rings are occasionally installed on the impeller.

(2) **Operation**

(a) When the pump is operating, the impeller rotates at high speed, drwing water into its center, near the shaft. The resultant centrifugal force imparts energy to the water,

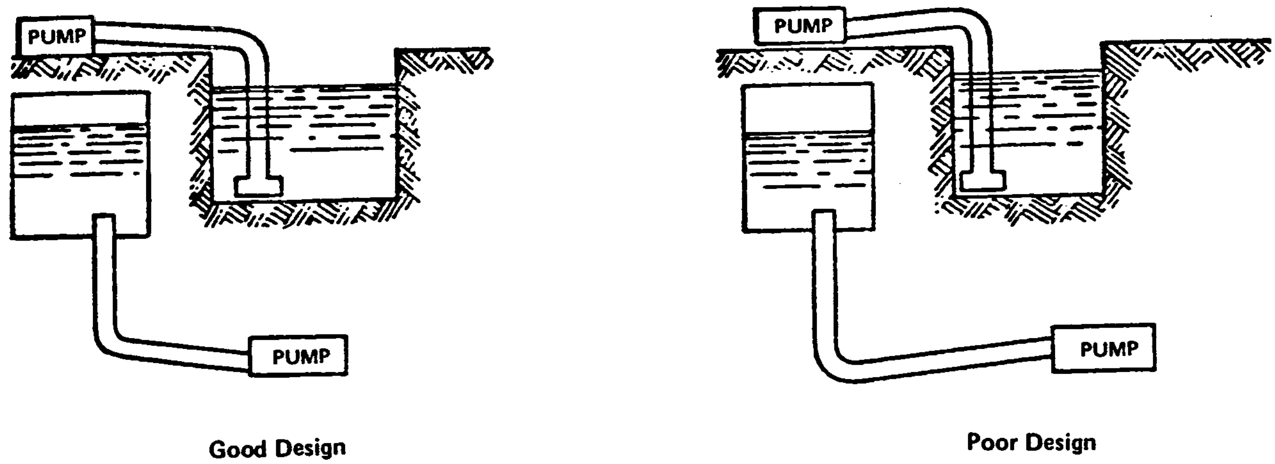

FIGURE 2-105A. MAINTAIN PROPER SLOPE TO SUCTION LINE

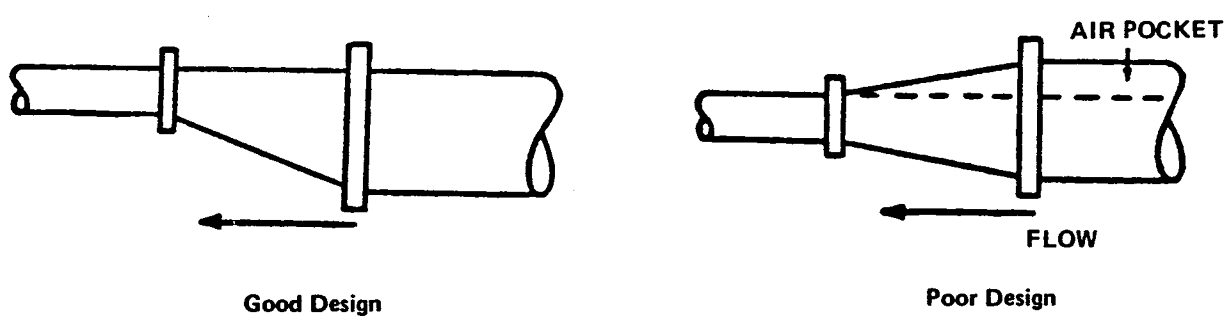

FIGURE 2-105B. SUCTION LINE INSTALLATION

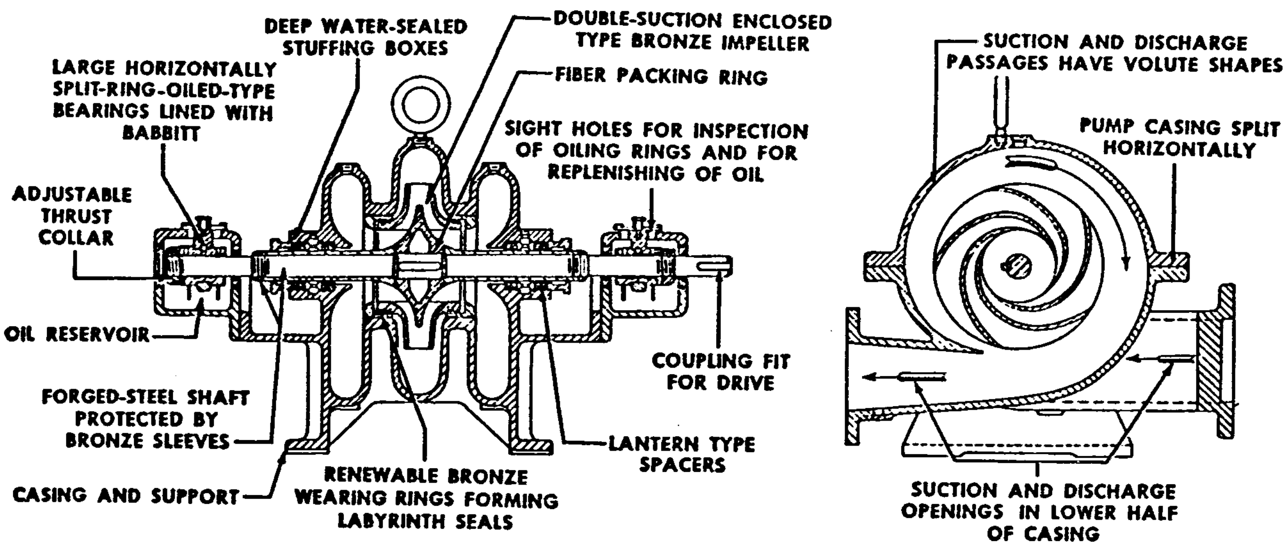

FIGURE 2-106. CENTRIFUGAL PUMP

which is forced outward. As this occurs, the partial vacuum produced at the inlet draws additional water. The casing must transform the velocity of water leaving the impeller into pressure with minimum loss. This is done in the pump shown by making the casing in the form of a spiral, called a volute, and gradually increasing its cross-sectional area from its beginning to the pump discharge. The pump shown is called a single-stage pump because the water passes through only one impeller. Multistage pumps are used when it is necessary to operate against higher heads. In a multistage pump the water travels through successive impellers or stages until it has reached the desired head.

(b) The output of a centrifugal pump can be controlled by regulating the pump speed, providing a controlled recirculation line, or throttling the discharge. The recirculation line, or bypass, consists of a valved line between the pump discharge and suction. The output of the pump is decreased by opening this valve and recirculating the water through the pump. Throttling the discharge increases the prssure at the pump outlet, causing some of the fluid to slop and remain in the pump casing. Any of these control methods can be manual or automatic. A centrifugal pump must be equipped with a check valve on the discharge side to prevent backflow of water when ıe pump is inoperative. Centrifugal pumps are designed to deliver a given quantity of fluid against a specified discharge pressure or head. Every centrifugal pump has a maximum or shutoff head, above which it is unable to deliver any fluid. This fact should be taken into consideration when an increase in delivery pressure is contemplated. The shutoff head can sometimes be increased by substitution of a larger impeller, although a larger motor may also be required.

c. Reciprocating Piston Pumps. The direct-acting, steam-driven duplex pump is widely used because of its low initial cost, low maintenance, simple operation, and positive action. Simplex pumps are rarely used because of the wide fluctuation in fluid pressure at the pump discharge.

(1) A horizontal duplex piston pump is shown in figure 2-107. This type of pump consists of two single-cylinder pumps mounted side by side. The piston rod of one pump operates the steam valve of the other through a system of bell cranks, rocker arms, or links. The pistons move alternately so that the resultant discharge of water is essentially continuous. Steam is admitted for the full stroke and is not used expansively, resulting in high steam consumption for the amount of water handled. Each cylinder has two ports in each end, one of which admits steam while the other discharges it. This minimizes the required valve travel but leaves sufficient bearing surface between the steam ports and the main exhaust port to prevent steam leakage from one to the other. The steam which is trapped in the cylinder when the exhaust stroke nears completion provides a cushion to prevent the piston from striking the sylinder heads. Some pumps also have small hand- operated valves on the side of the steam chest to regulate the amount of cushioning by controlling the escape of the steam from the cyclinder. Maximum cushioning is desired with the pump operating at high speeds, and is obtained by closing the hand valve.

(2) The valves of a duplex pump do not overlap the edges of the ports with the valve in its midposition. The valves are held to their seats by the pressure differential acting on the two sides of the valve. Figure 2-108 shows the relative position of the working parts when pump and valve are in midposition. The illustrations indicate that the valves are not fastened rigidly to the stem and that there is lost motion between the valve and the stem. This lost motion is provided to force the pump to take a full stroke; otherwise, it would make only about a quarter stroke. The typical operations of the pump are also due to this lost motion. When one piston has completed its stroke, it pauses and goes into reverse only after the second piston has reached the end of its stroke and moved its valve. One piston is always in position to move so that the pump goes into operation as soon as the steam valve is opened.

d. Rotary Positive Displacement Pumps. Rotary positive displacement pumps use gears, screws, or sliding vanes to more a volume of fluid through the pump. Rotary positive displacement pumps are most commonly used in Army boiler plants to pump fuel oil. Very close tolerances are maintained between the pump internals to minimize slippage of fluid. Slippage in a positive displacement pump may be less than 0.5%, while slippage of 50 percent or more is common in centrifugal pumps. These pumps can thus operate at high efficiencies and pressures. Rotary positive displacement pumps should be equipped with relief valves to protect against overpressurization. While centrifugal pumps may be controlled by throttled flow, rotary positive displacement pumps are controlled by recirculating a portion of the pumped fluid back to the tank or the pump suction.

e. Jet Pumps/Injectors. An injector is a jet pump used to feed water into a boiler, where its high thermal efficiency justifies its use. Most of the heat, in the form of steam, used to operate the pump is returned to the boiler with the water. The injector is convenient, cheap, compact, efficient, and has no moving parts. It delivers warm water into the boiler without preheating, and has no exhaust to dispose of. It cannot be used to pump hot water and can handle a maximum water temperature of about 140 F. Excessive preheating of feedwater passing through the injector often causes impurities to drop into the tubes, scaling them so heavily that the injector fails to function.

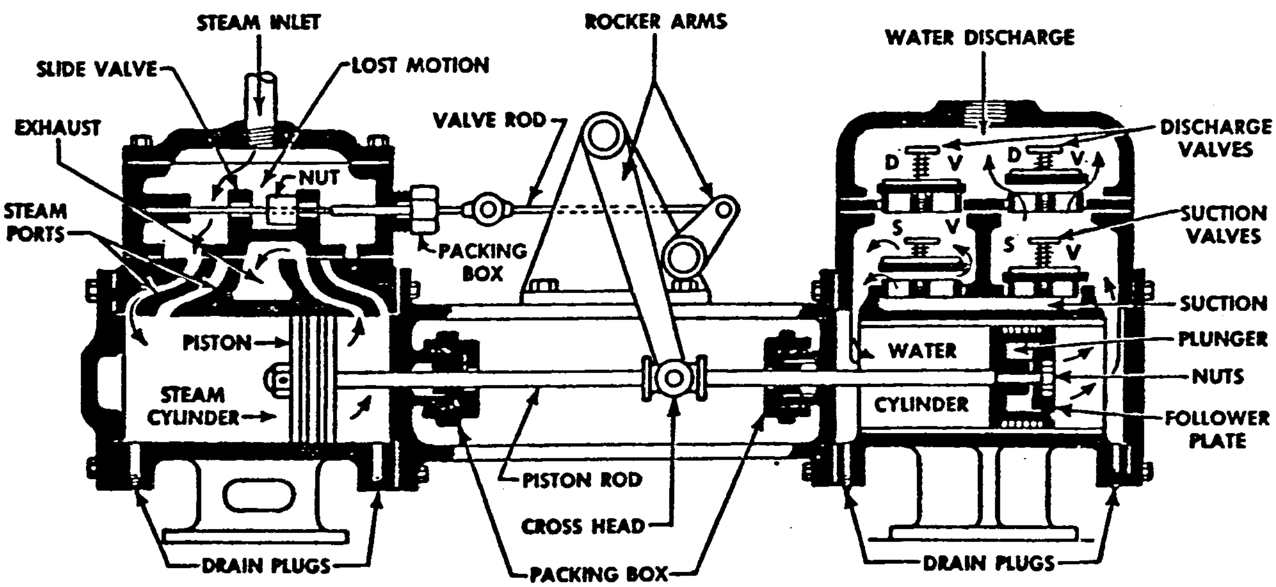

FIGURE 2-107. RECIPROCATING PISTON PUMP

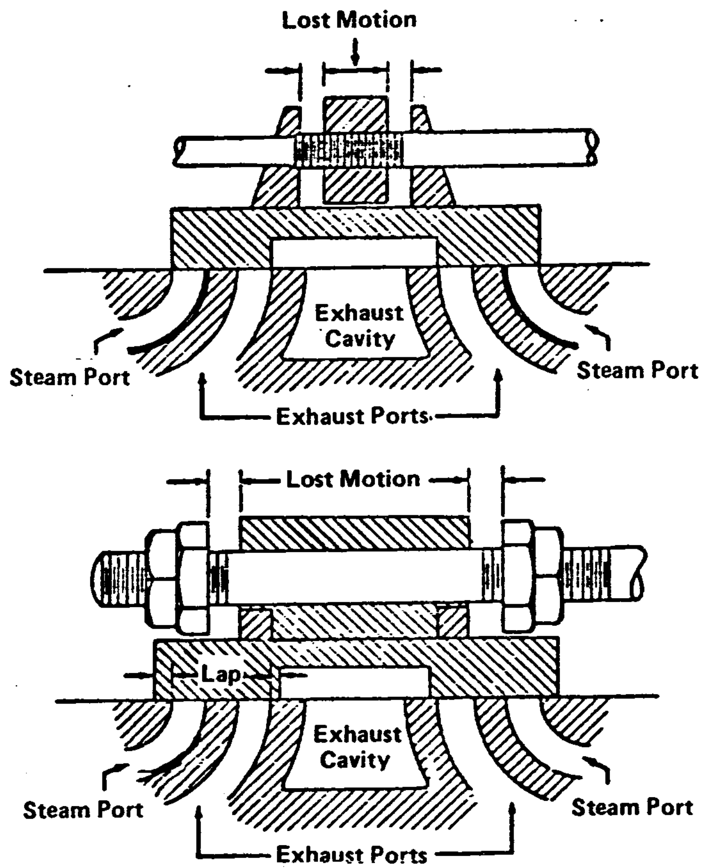

FIGURE 2-108. TWO METHODS OF PROVIDING LOST MOTION

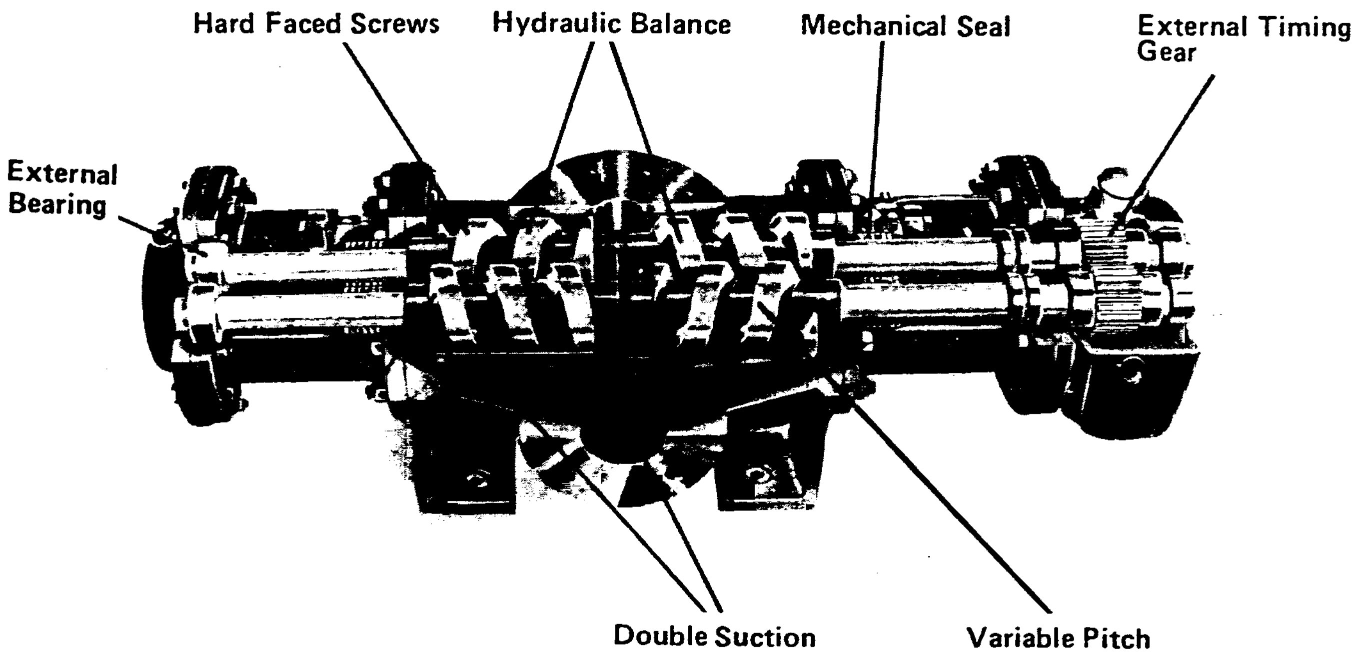

FIGURE 2-109A. ROTARY SCREW PUMP

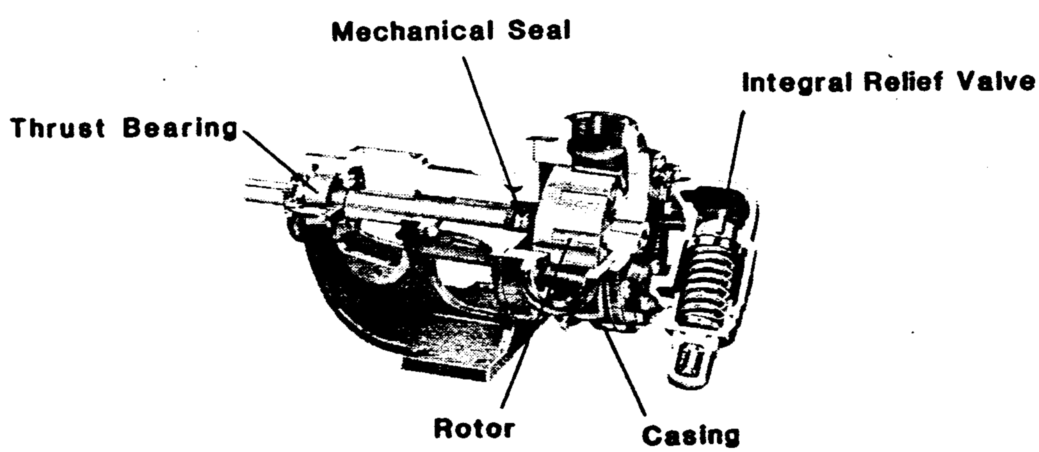

FIGURE 2-109B. ROTARY GEAR PUMP

The essential parts of an injector are the steam tube, combining and delivery tubes, and the necessary casing to guide the water to and from these tubes. Reference figure 2-110. The shape of the steam tube is designed in the shape of a venturi to increase the velocity of the steam passing through the tube. As a result of this high velocity, air is partially evacuated from the inlet line, causing the water to rise until it contacts the steam at the entrance of the combining tube. The steam is condensed and imparts considerable velocity to the water. The condensing steam reduces its volume and thus maintains the vacuum. The combining tube further increases the velocity of the moving mass of water, enabling it to cross the opening to the delivery tube. The water velocity opens a check valve and water enters the boiler against the boiler pressure. An overflow is provided to remove water when the injector is started. No water should appear at the overflow if the injector is operating properly. Injectors can be hand-starting, automatic, single-tube, or doule-tube. An automatic injector will resume its flow after an interruption without any attention from the operator. The injector operates satisfactorily under a constant load and pressure but becomes unreliable when operating with fluctuating pressure. Due to this fact and to the low temperature 'imitations, injectors are rarely used on modern installations. Injector failures are rarely used on modern installations. Injector failures are most often caused by excessive suction lift, hot water, clogged strainer or suctin line, and fluctuating pressurs.

f. Boiler Feed Pumps. The boiler feed pump is probably the single most important auxiliary in the boiler plant. It must be operated continuously while the boiler is in operation, and at a rate of discharge equal to the rating of the boiler. The Code requires the boiler to have two methods of feeding water, to ensure that an adequate supply is available at all times. Reciprocating and jet pumps can be used for this purpose, but centrifugal pumps are most commonly used in modern stationary practice. Centrifugal pumps have the advantages of small size, high speed, low chance of boiler water contamination with oil, and continuous steady flow.

(1) **Reciprocating Pump Application.** The area of the steam cylinder of a reciprocating pump ranges from two to three times that of the water piston or plunger to allow for friction losses and to permit the pump operation at reduced steam pressures. A boiler feed pump is required to pump against a total head ranging from 1.1 to 1.5 times the boiler pressure. A reciprocating pump must be sized to provide the desired water discharge capacity with the pump operating at approximarely one-half the mzximum stroke rate. This allows for pump wear and provides a margin in an emergency, such as low water or ruptured tubes. Reciprocating pumps of the direct-acting duplex type are sometimes used for small capacities and moderate pressures. They consume approximately 5% of the steam produced by the boiler, but since the exhause is utilized to heat the feedwater, the net heat consumed by the pump can be less than 1%.

(2) **Centrifugal Pump Application.** Centrifugal pumps for boiler-feed applications must be sized to develop enough head and capacity to feed the boiler under all conditions. A centrifugal pump may be driven by a steam turbine or a variable- or constant-speed motor. The method used to control output depends primarily on the type of drive used. Any centrifugal pump used to pump hot water must be provided with an adequate flow of water at all times. Centrifugal pumps quickly become steam-bound and stop pumping under certain conditions, and may be damaged if permitted to operate under those conditions for any length of time.

g. Condensate Pumps. Reciprocating, positive-displacement rotary, and centrifugal pumps are used for this service. Heating systems generally use an automatic float-operated centrifugal pump. The condensate drains to a return tank or reservoir, and a float operates a motor switch which starts and stops the centrifugal pump. In one arrangement, the motor is on tip of the tank and the pump is at the bottom. In another arrangement, the pump and motor are mounted outside and below the re turn tank.

h. Vacuum Pumps. Reciprocating, jet, and positive-displacement rotary-type pumps may be used for vacuum service. A centrifugal pump can be used to supply water to the jet, which actually maintains the vacuum. Reciprocating pumps, arranged to remove both condensate and air at the same time, are called wet vacuum pumps. This is a common arrangement and is used with small condensing turbines or engines. Smaller clearances in the water end characterize pumps used for this service. A poump which removes only air is known as a dry vacuum pump. The vacuum pump in a vacuum-return heating system must handle both air and water. One method of doing this is to use a pump with two impellers mounted on a shaft. One impelller handles the water and the other the air. The condensate flows into the receiver and enters the pump. An automatic control actuated by the water level and the pressure in the receiver (which is below atmospheric) starts and stops the pump as required. This arrangement can maintain a vacuum of 10 to 18 ilnches of mercury in a system which is reasonably free from leaks.

2-38. FORCED DRAFT FANS.

Forced draft (FD) fans are applied to push the combustion air through the burner into the furnace. If an induced draft fan is not supplied, the forced draft fans must also

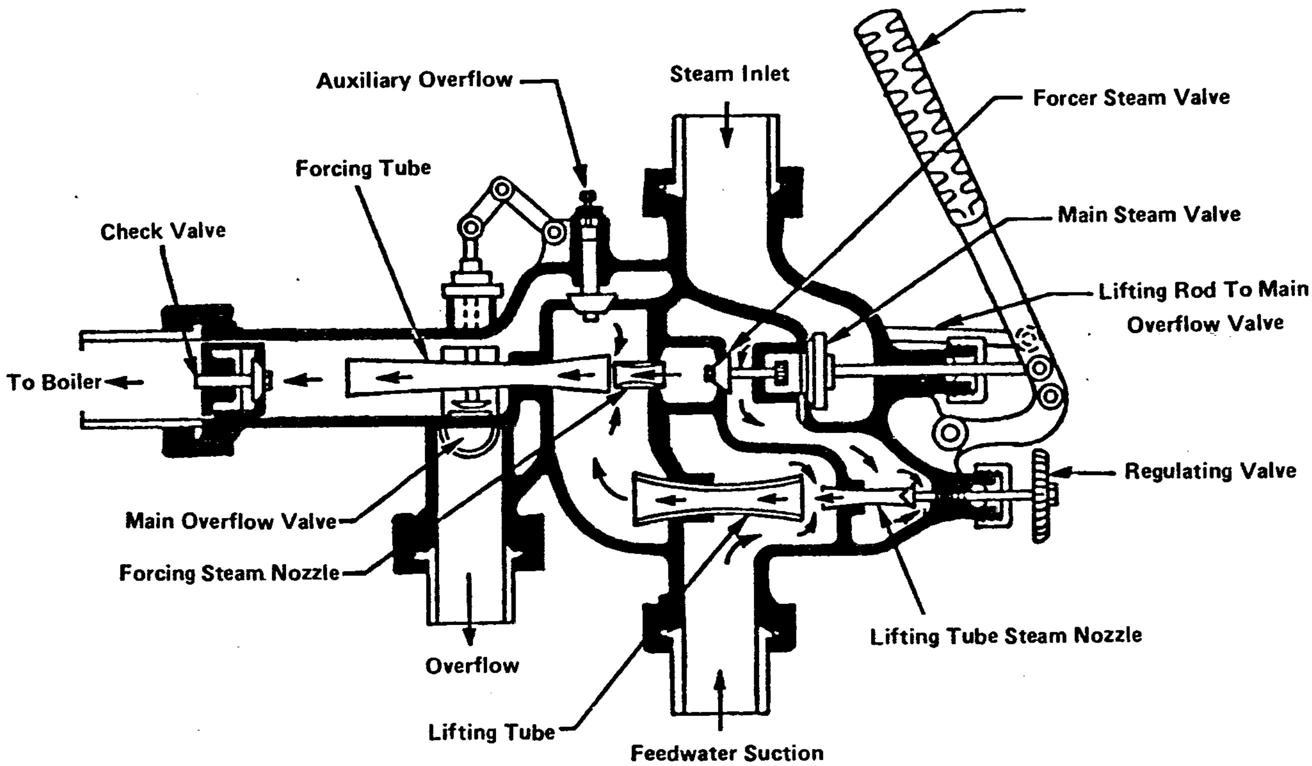

FIGURE 2-110. STEAM INJECTOR

push the products of combustion through the boiler to the stack. Both centrifugal and axial fans are used, with centrifugal units being more common. Centrifugal fans include the following blade designs: radial, forward curved, forward curved / backward inclined, backward inclined, and airfoil / backward inclined. Backward inclined and airfoil / backward inclined fans are most commonly used for forced draft fan service because of their high efficiency, stable operation, and non-overloading horsepower characteristics. Forced draft fans are required to operate over a load range of approximately 25 to 100 percent of capacity. This is accomplished primarily by the use of dampers. Three types of dampers are used: inlet dampers, parallel blade outlet dampers, and opposed blade outlet dampers. Figures 2-111 illustrates a forced draft fan equipped with inlet vane dampers. Figure 2-112 illustrates a typical parallel blade outlet damper. Inlet gvane dampers control air flow through the fan by prespinning the entering air. Each position of an inlet vane damper in effect creates a new fan and horsepower curve, as shown in figure 2-113. This results in improved control range and horsepower savings over outlet damper applications which control by creating a static pressure on the fan. The increased statis pressure reduces flow and causes the operating point to move back up the fan curce (reference figure 2-114). Opposed blade outlet dampers provide a greater control range than parallel blade outlet dampers, which operate best in the 70 to 100 percent capacity range.

2-39. INDUCED DRAFT FANS.

Induced draft (ID) fans are used to exhaust the products of combustion from the boiler. Maintaining balanced draft conditions in the furnace improves boiler operation and provides energy to move the flue gases at the velocities needed for good heat transfer. Induced draft fans are subjected to more severe service conditions than forced draft fans, because they must handle larger volumes of gas at high temperatures and containing ash particles. The physical characteristics of ID fans must therefore be different from those of forced draft fans. Airfoil blades are not recommended for ID fan service. Backward inclined fans are acceptable for non-abrasive gas service, while radial or radial tip blades and forward curved / backward inclined fans are recommended for abrasive service. The higher temperature of gases handled by the ID fan sometimes makes it necessary to use water-cooled bearings to prevent overheating. Inlet damper controls or variable speed drives are used to control induced draft fan capacity.

2-40. STACKS. FLUES. AND DUCTS.

Stacks or chimneys are necessary to discharge the products of combustion at a sufficiently high elevation to prevent nuisance due to low-flying smoke, soot, and ash. A certain amount of draft is also required to conduct the flue gases through the furnace, boiler, tubes, economizers, air heaters, and dust collectors, and the stack can help to produce part of this draft. The height of the stack necessary to meet the first requirement is often enough to also produce the draft necessary to meet the second requirement. The amount of draft available from a stack depends on the height and diameter of the stack, the amount of flue gas flowing through it, the elevation above sea level, and the difference between temperature of the outside air and average temperature of gases inside the stack. Excessive stack temperatures are undesirable, because they represent a heat loss and efficiency reduction.

a. Stack Construction. Stacks are built of steel plate, masonry, and reinforced concrete. Caged ladders should be installed. All stack guys should be kept clear of walkways and roads and, where subject to hazardous contact, should be properly guarded. Stacks are provided with means of cleaning ash, soot, or water from their base, the means depending mainly on the size of the stack.

(1) **Steel.** The advantages of steel stacks over masonry or reinforced concrete are reduced construction time, lowr weight, smaller wind surface, and lower initial cost. Major disadvantages are higher maintenance cost and shorter life. Steel stacks may be either self-supporting or guyed, single-wall or double-wall construction, and lined or unlined. Unlined guyed stacks usually are used on smaller installations. This type of stack can be supported by the boiler smoke box, the building structure, or a separate foundation. Two sets of four guy wires each are usually used to hold the stack erect. Steel stacks over 72 inches in diameter are normally self-supporting. They are typically lined with refractory or insulation to protect the metal from the corrosive attack of the flue gases and to improve the performance of the stack by minimizing cooling of flue gases. The self-supporting stack is usually mounted on its own foundation oor on the building structure framework. Stub and venturi stacks are typically of steel construction and usually extend no more than about 20 feet above the boiler. When these stacks are used they contribute little to the draft requirements, which must be then supplied entirely by forced-and / or induced-draft fans.

(2) **Brick.** The modern brick chimney built of special radial brick or block is very satisfactory, its major disadvantage being its higher cost. This type of stack is normally lined with fire brick for about one-fifth of its height and must be protected from lightning.

b. Flues and Ducts. Flues are used to interconnect boiler outlets, economizers, air heaters, and stacks. Ducts are used to interconnect forced-draft fans, air heaters, and windboxes or combustin air plenums. Flues and ducts are usually made of steel. Expansion joints are provided to

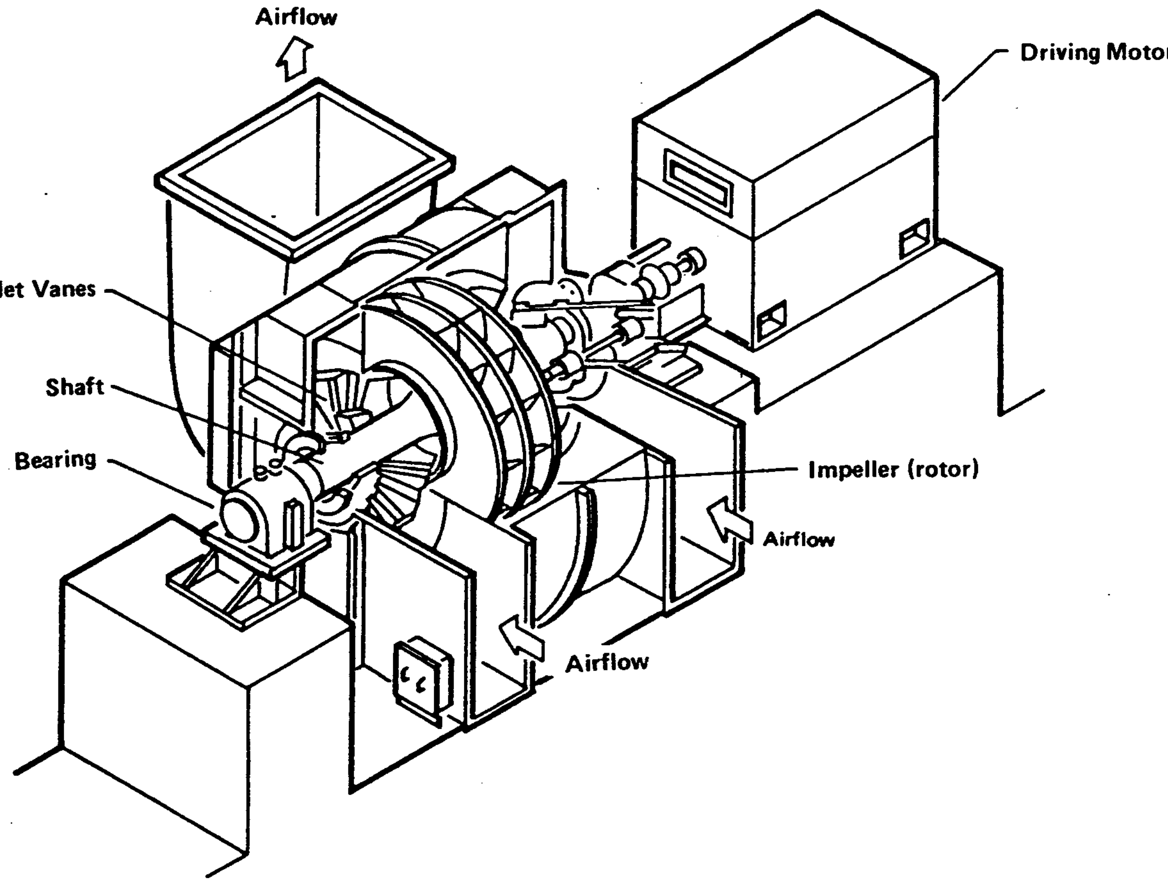

FIGURE 2-111. FORCED DRAFT FAN WITH INLET DAMPER

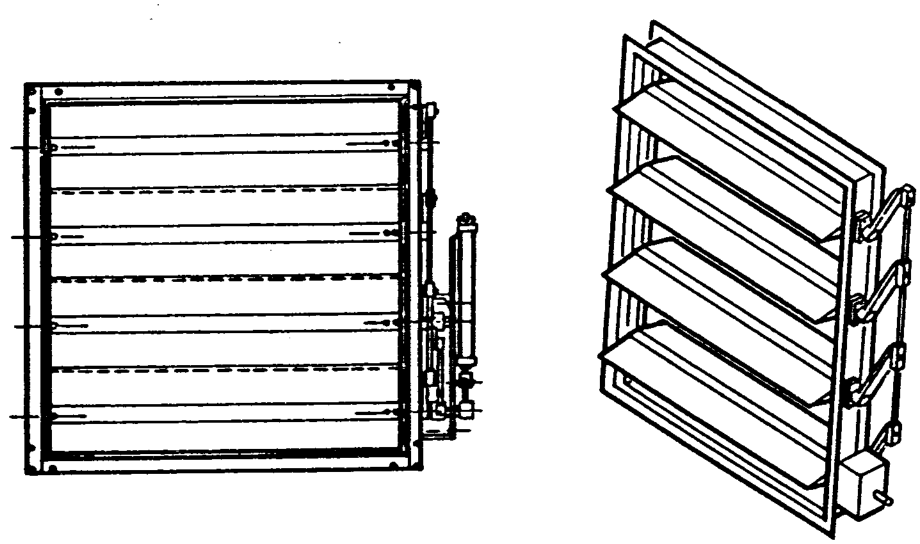

FIGURE 2-112. TYPICAL OUTLET FAN DAMPERS

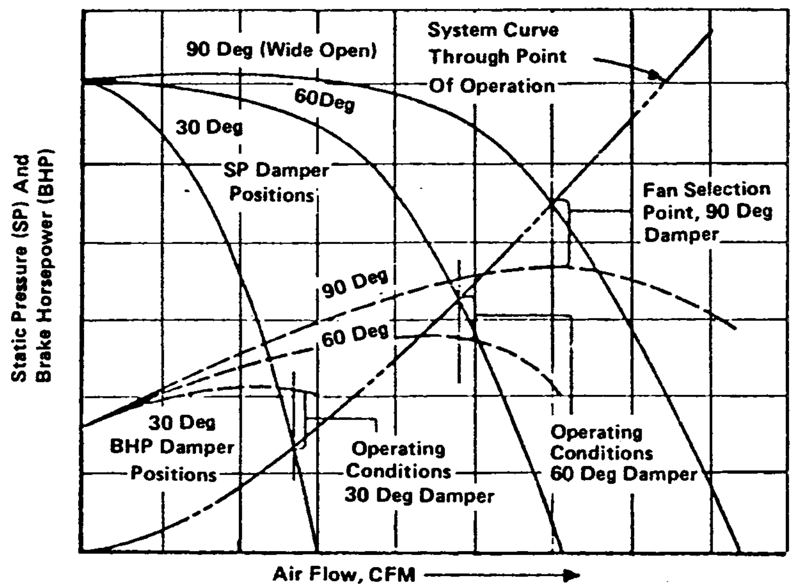

FIGURE 2-113. FAN CURVES FOR DIFFERENT INLET VANE POSITIONS

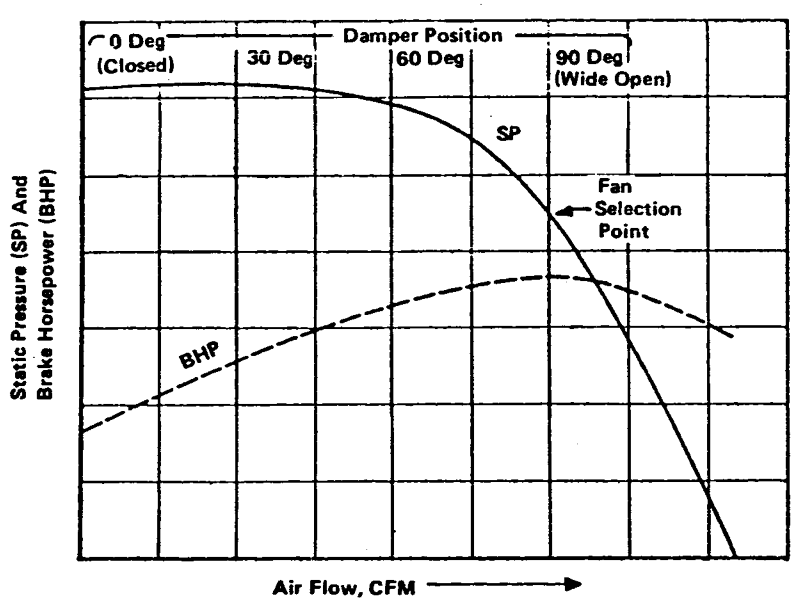

FIGURE 2-114. FAN CURVE FOR FAN WITH OUTLET DAMPER

allow for expansion and contraction. All flues or ducts carrying heated air or gases should be insulated to minimize radiation losses. Outside insulation is preferred for its maintainability. Flues and ducts are designed to be as short as possible, free from sharp bends or abrupt changes in cross-sectional area, and of adequate cross-sectional area to minimize draft loss at the design flow rates.

2-41. STEAM TURBINES.

The reciprocating steam engine with its need for oil lubrication and the resulting contaminated steam has been replaced by steam turbines and electric motors. Steam turbine driven boiler plant auxiliaries are generally economical only if the exhaust steam can be used for feedwater or other heating applications. The steam turbine uses a rotating wheel, with buckets or blades uniformly spaed around its circumference to transform the heat energy of steam into mechanical energy or work. Steam, expanding through a nozzle, is directed against these buckets and causes the wheel to turn. Various types of steam turbines differ in the construction and arrangement of the nozzles, steam passages, and buckets. The steam turbine is essentially a high-speed machine; it is best used with direct connection to electric generators, pumps and fans, and with geared connection to low-speed machinery. The common non-condensing turbine opoerates at an efficiency of only 20 percent. Only special circumstances, such as the necessity for oil-free exhaust steam, can justify the use of a small turbine for any purposes other than standby or emergency. Figure 2-115 shows a single-stage impulse non-condensing steam turbine.

2-42. ELECTRIC MOTORS.

Electric motors can be grouped into three general classes based on power source. These classes are direct current, single-phase alternative current (AC), and three-phase AC. Three-phase motors are available in squirrel cage, synchronous, and wound rotor. The squirrel-cage motor has become dominant because of its low cost, high reliability, high efficiency over a wide load range, and high starting torque, and it is estimated that 90% of all electric motor energy is consumed by three-phase squirrel motors. Not all squirrel-cage motors perform equally, however. When the need to replace or install a new motor exists, modern higher efficiency and higher power factor designs should be considered. Economic analysis usually justifies the slightly higher initial cost of high-efficiency motors.

2-43. ELECTRICAL EQUIPMENT.

Electrical equipment used in central plans includes motors, motor starters, controls, circuit breakers, switchgear, transformers, fire protection, lighting, conduit, and wiring. Opoeration of these devices involves the use of voltages which are dangerous to life. Operating personnel must observe safety regulations found in Army Manual TM 5-682. Additional information on electrical equipment can be found in Army Manuals TM 5-680G, TM 5-683, TM 5-684, and TM 5-687.

2-44. VARIABLE SPEED DRIVES.

Electrical, mechanical, and fluid variable speed drives are available. Electrical drives include multiple speed motors, variable frequency controls, and variable voltage controls. The development of solid state components has allowed the design of variable frequency controls which can opoerate at high efficiency over a wide load range. Mechanical variable speed drives include belts with adjustable pulleys, gear reducers, and geared transmission. FLuid drives include a variety of hydraulic couplings.

2-45. AIR COMPRESSORS.

Three basic types of air compressors are available: reciprocating, rotary, and centrifugal. Air compressors may be further classified as oil-free or lubricated. Air compressors used in Army installations are comparatively small units, with final discharge pressures of approximate' 100 psi. They are typically of rotary screw or single- o. two-stage reciprocating design. These two types are discussed below. TM 5-810-4 may be referenced for additional information on compressed air systems.

a. Compressor Types

(1) **Reciprocating.** The reciprocating compressor is a poston-type, positive displacement machine. Air volumes can range up to approximately 6,000 CFM. Two-stage compressors are frequently used, because they require less power to compress a given quantity of air than do single-stage machines. Cylinders and intercoolers of two-stage machines may be cooled by either air or water. The need for shielding or baffliing structures for noise attenuation requires investigation when reciprocating compressors are to be used.

(2) **Rotary Screw.** Rotary screw compressors are also classified as positive displacement machines. They operate by passing the inlet air through an inlet valve, and then compressing it through the action of two helical screws rotating against one anothert. Air volumes can range as high as 3,000 CFM but are more typically in the 100 to 150 CFM. Packaged units are readily available in sizes up to 500 CFM which incorporate all the necessary filters, coalescers and coolers into a single, factory designed and assembled unit. Liquid sealed rotary screw-type units are available up to about 300 CFM and can provide oil-fre air. This type of compressor is recommended in food processing or health care facilities but is not often used

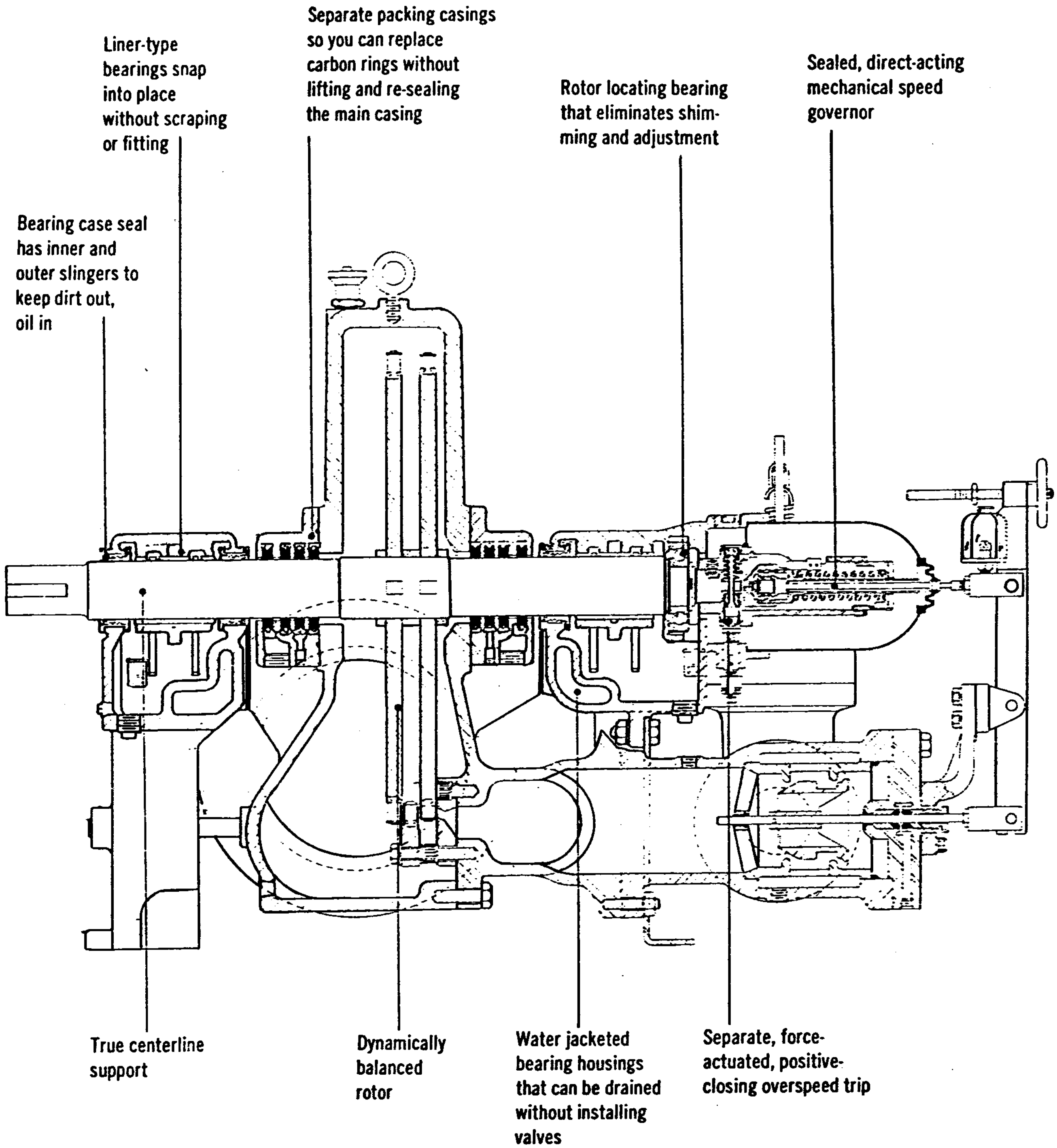

FIGURE 2-115. SINGLE-STAGE IMPULSE NON-CONDENSING TURBINE

in boiler plants. It is more common to provide oil-free air to boiler plants by means of filters nd separators in combination with one of the compressor types discussed above.

b. Capacity of Air Compressors. Total air requirement should be based not upon the total of individual maximum requirements but upon the sum of average air consumption of air-operated devices. Compressor capacity should be based upon the calculation procedure explained in TM 5-810-4.

c. Aftercoolers. In the process of compressing air, approximately 80 percent of the energy delivered by the electric motor becomes heat energy stored in the compressed air at elevated temperature. Aftercoolers are required to cool the air to a more usable temperature. An aftercooler is a heat exchanger which is sized to cool the air below the dew point so as to allow water and oil vapors to condense. A moisture separator is attached to remove the condensed vapors. The aftercooler is normally cooled with water, but it may also use air as its heat exchanger medium. d. Air Dryers. Some compressed air applications require moisture removal in addition to that provided by the aftercooler. Such applications in the boiler plant include pneumatic tools, opoeration of pneumatic drives on dampers or valves, and instrument air. For these applications, a supplemental dryer is required. THree basic categories exist: refrigeration dryers, regenerative dryers, and deliquescent dryers. Regenerative dryers are the type usually used in boiler plants, and are discussed here. Information on the other types may be obtained from manufacturers or from TM 5-810-4. Regenerative dryers are further broken down into three types: heatless desiccant, heat regenerative, and low temperature regenerative.

(1) **Heatless Desiccant Dryers.** Heatless desiccant regeneration passes a quantity of dried (purge) ari through the offstream bed. No external heat is applied. This type should be selected with a field-adjustable purge control so that the purge rate (and therefore the pressure dew point) can be adjusted to accommodate seasonal variations in ambient temperature, thereby reducing operating costs. Heatless dryers are capable of providing minus 150 F pressure dew point. Maintenance costs are low, since there are few moving parts. With adequate prefiltering to remove oil, desiccant replacement requirements are minimal.

(2) **Heat Regenerative Dryers.** Heat regenerative dryers utilize heat from an external source (either electric or steam) in conjunction with purge air to regenerate the offstream tower. By reducing the amount of purge air required to regeneration, the heat regenerative dryer operating costs can be outweighed by maintenance costs and downtime.

(3) **Low-Temperature Regenerative.** Low-temperature regenerative (heat pump) dryers utilize thermal energy from the inlet air to heat the offstream tower for regeneration. No electric heaters or steam are used. This type of dryer provides the economy of refrigerated drying and the low-pressure dew-point capability of desiccant drying. Refrigeration cooling is used to remove most of the incoming moisture and to cool the onstream tower for high adsorption efficiency. This system saves energy, since the heat energy removed from the inlet stream is recycled by the refrigeration compressor and discharged to the offstream tower for regeneration. Stable pressure dew points down to minus 100 F are realized with this type.

e. Air Receivers. Air receivers are steel pressure vessels, constructed in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, which are sized to dampen pulsations entering the compressor discharge line; to serve as a reservoir for sudden or unusually heavy demands in excess of compressor capacity; to prevent too frequent loading and unloading of the compressor, and to allow moisture and oil vapor carryover from the aftercooler to precipitate. Recommendations for receiver size and mounting are contained in TM 5-810-4. Drainage valves and piping, safety valves, and prssure gages must be installed in accordance with the Code.

2-46. STEAM TRAPS.

Steam traps are used to discharge condensate and air but not steam from a pipeline or heat exchanger. No single type of trap is ideal for every situation. The four major types of steam traps are thermostatic, float and thermostatic, disc/theremodynamic, and interted bucket. These are discussed below. Orifice or impulse traps are also produced but operate by discharging steam continuously and are therefore nor recommended. This waste, as well as the wasting of steam from defective or damaged traps, represents an energy loss that is not acceptable. Proper maintenance of steam traps is discussed in paragraph 5-40.

a. Thermostatic Steam Traps. Thermostatic traps can be further subdivided into balanced-pressure thermostatic traps, liquid expansion traps, and bimetallic traps. All three subtypes work by sensing the difference between steam temperature and cooler condensate temperature, utilizing an expanding bellows or bimetal strip to opoerate a valve head. They usually discharge condensate below steam temperature and therefore require a collecting leg before the trap to allow for some condensate colliIng. A balanced pressure thermostatic trap is illustrated in figure 2-116. Thermostatic traps are typically used in low and medium pressure applications such as steam radiators, submerged heating coils, and steam tracing lines.

b. Float and Thermostatic Steam Traps. Float and thermostatic traps (figure 2-117) are recommended for use

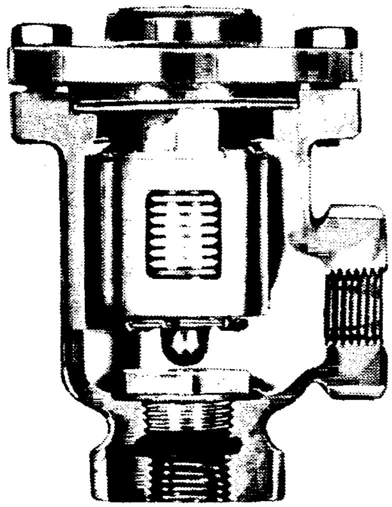

FIGURE 2-116. THERMOSTATIC STEAM TRAP

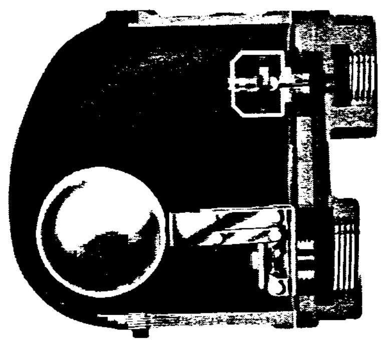

FIGURE 2-117. FLOAT AND THERMOSTATIC STEAM TRAP

wherever possible. Their valve seat is always under water, preventing any steam loss. The discharge is continuous and modulates with the condensing rate, and it is unaffected by changes in inlet pressure. A separate thermostatic air vent independently purges air, giving a fast startup, and discharges in parallel with the main valve seat without affecting its operation. Typical applications of float and thermostatic traps are air unit heaters, hot water heaters, heat exchangers and converters.

c. Disc/Thermodynamic Steam Traps. Disc/thermodynamic traps (figure 2-118) are widely used due to their small size, wide pressure range, one moving part, and resistance to water hammer and corrosion. Because operation of each model depends on the manufacturers seat and disc design, results may vary widely. Many are prone to air-binding on startup, operate below steam temperature (causing waterlogging), have a relatively short life due to soft seat and disc materials, and contain a bleed slot which causes rapid cycling and steam loss. Properly designed disc/thermodynamic traps can overcome these problems and allow effective and efficient operation. They are typically used on high-pressure or superheated steam drip legs, steam trace lines, and unit heaters.

d. Inverted Bucket Steam Traps. Inverted bucket traps (figure 2-119) have been in existence for many years, and their low initial cost helps keep them popular, although in every application superior results can be obtained with another type of trap. They consume a small amount of steam in operation and can blow fully open if they lose their prime due to oversizing or a rapid drop in inlet pressure. Their discharge is intermittent, not continuous. Typical appliocations include high pressure indoor steam main drips and submerged heating coils.

2-47. PIPING SYSTEMS.

Piping (and tubing) systems are used in the central boiler plant to transport a wide variety of fluids, including among others water, steam, oil, natural gas, and compressed air. The following section is intended to provide a brief overview of some of the components and considerations which are involved in piping and tubing systems. The word piping in this manual can generally be assumed to mean both pipe and tube. Strictly speaking, however, there is a difference between pipe and tube, and this is discussed briefly in subparagraph c.

a. Design Codes. Design of boiler plant piping is generally governed by design codes and industry standards. The ASME Boiler and Pressure Vessel Code, Section I, which was discussed in paragraph 2-9 as it appplies to boilers and accessories, also covers certain portions of the piping around the boiler. Much of the balance of the piping in a boiler plant is covered by the Power Piping Code, ANSI B31.1. Some additional design codes and their applicability are given in table 2-8. These design codes generally specify the materials that may be used within their scope, how the piping sizes and thicknesses must be determined, how the pipe must be supported, what types of fittings, joints, and accessories may be used, and other provisions. Although these codes are w ritten primarily for the pipine designer or engineer, a general knowledge of their provisions is useful to the operator as well.

b. Materials. Piping materials are generally specified by the design code under which the system is built. The most common piping material lin the boiler plant is steel. Steel pipe is strong, relatively easily worked, and available in a wide variety of sizes to fit most applications of pressure, temperature, and fluid. Other piping materials which are used for specific applications include copper, stainless steel, cast iron, and plastic. Some common applications of the various materials are included in table 2-9.

c. Sizing. Standard specification of size is the primary difference between pipes and tubes. Pipe size is specified by Nominal Pipe Size (NPS) and Schedule. Tube size is given by outside diameter and wall thickness.

(1) **Pipe Size.** Nominal pipe size or NPS refers to the diameter of the pipe. Nominal pipe sizes range from ⅛ inch up to at least 30 inches, in standard increments. The outside diameter for a given NPS is always the same, while the inside dismeter varies depending upon the schedule. Schedule refers to the wall thickness and is generally listed as Schedule 40, Schedule 80, Schedule 160, etc. Earlier practice, which is still used on occasion, was to refer to schedules by designations such as Standard (STD), Extra Strong (XS), or Double Extra Strong (XXS). The dimensions and tolerances corresponding to the nominal sizes and schedules are established by ANSI standards. There is no easy way, other than referring to a chart, to determine the actual dimensions of a given nominal pipe size. For instance, 1 inch NPS, Schedule 80 pipe has an outside diameter of 1.315 inches, a wall thickness of 0.179 inch, and an inside diameter of 0.957 inch.

(2) **Tubing Size.** Tubing size is specified by Outside Diameter (OD) and wall thickness. Although tubing theoretically is available in almost any diameter, ranging from a few hundredths of an inch up to several feet, in practice, tubing in a boiler plant is limited to sizes of about ⅛ inch to 1 inch. Tubing in common use in the boiler plant is generally either copper or stainless steel. The major exception to this rule is within the boiler itself. Boiler manufacturers generally use tubing rather than pipe, and for the most part use carbon or low allow steel.

(3) **Determination of Proper Size.** Piping systems must be sized with regard to a number of criteria, including type and quantity of fluid to be transported, pressure and

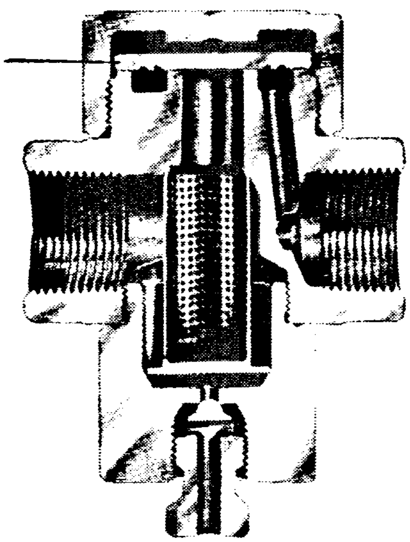

FIGURE 2-118. DISC/THERMODYNAMIC STEAM TRAP

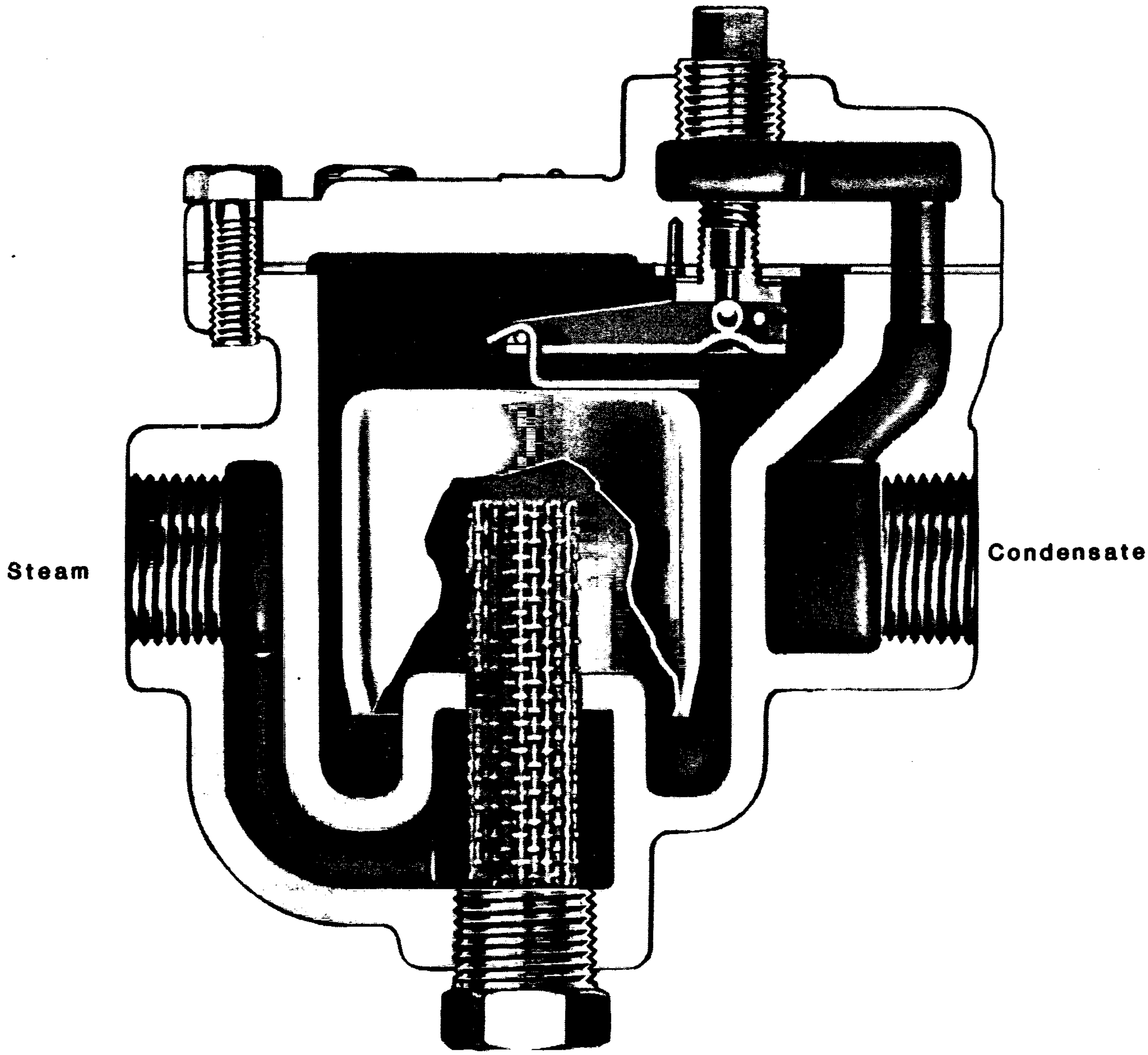

FIGURE 2-119. INVERTED BUCKET STEAM TRAP

Table 2-8. Piping Codes and Standards
For Boiler Plants

Sponsoring Agency	Identification	Title	Coverage
ASME	Boiler and Pressure Vessel Code - Section I	Power Boilers	All piping connected to boiler up to first (in some cases second) shut-off valves
	Boiler and Pressure Vessel Code - Section IX	Welding Qualifications	Qualifications for welders on power piping systems
ANSI	B31.1	Power Piping	All boiler plant piping beyond the jurisdiction of ASME BPV I.
	B36 Series	Iron and Steel Pipe	Materials and dimensions
	B16 Series	Pipe, Flanges, and Fittings	Materials, dimensions, stresses, and pressure/temperature ratings
	B18 Series	Bolts and Nuts	Bolted connections
ASTM		Testing Materials	Physical properties of materials specified in ASME and ANSI codes
NEMA	TU4 and SM20	Steam Turbines	Allowable reactions and movements on turbines from piping
NFPA	13, 15, et al.	Sprinkler Systems and Automatic Spray Systems	Piping for fire protection systems
AWS	D10.9	Qualifications of Welding Procedures and Welders for Piping and Tubing	Qualifications for welding of fire protection systems

Table 2-9. Typical Piping Material Applications

Material	Typical Applications	Typical Joints[1]
Carbon Steel	High pressure steam, water, fuel oil, compressed air, and natural gas. Almost any fluid, with the exception of certain corrosive types, up to about 750F	Screwed, socket- or butt-welded, flanged
Low Alloy Steel	Superheated steam, up to 1000F	Welded
Stainless Steel	Chemical and corrosive applications[2], steam above 1000F, instrument tubing	Socket- or butt-welded, flanged; tubing may use flared or compression fittings
Cast Iron	Floor and roof drains; water supply, sanitary piping; low pressure and temperature applications	Bell and spigot, mechanical groove-lock joints
Copper	Plumbing, potable water; instrument tubing	Soldered, flared, or compression fittings
Plastic (PVS, ABS)	Sanitary drains, non-potable water; miscellaneous low pressure applications	Solvent welded

NOTES:
1. Selection of proper joint must be based on design code.
2. Extreme care must be used in selection of proper alloys for corrosive service.

temperature conditions, allowable velocities, and pressure loss. These calculations can become quite sophisticated and are outside the scopoe of this manual. The pertinent design codes should be consulted for guidance.

d. Fittings and Joints. Pipe ;and tubing may be joined in a variety of ways, including threading, welding, flanges, a variety of mechanical coupling-type joints, soldering (for copper and brass), and solvent welding (for plastics). All of these methods are common, and the type used in a particular application is usually specified by the design code. In steel piping, high pressure systems such as steam or boiler feedwater commonly use welded joints, as do systems which are larger than approximately 2 to 3 inches in diameter. Smaller diameter systems in steel pipe may be threaded or socket welded. Flanges are often used when the piping must be disassembled periodically, for instance to perform maintenance on valves or other components. Fittings and flanges are available in materials and thicknesses to correspond to the pressure and temperature requirements of the piping system.

e. Pipe Supports. Proper support of piping systems requires sophisticated design calculations and is outside the scope of this manual. Some of the general criteria which must be considered in making these calculations are discussed below.

(1) **Allowable Stress.** The design codes for each application generally provide allowable stress levels for each material. These levels have been determined by experience to have adequate safety margin, and they must be adhered to. Allowable stress for a given material is a function of temperature and decreases at higher temperatures.

(2) **Expansion/Flexibility.** As the temperature of a pipe changes, the pipe moves due to expansion and contraction. Provisions must be made in the piping support system to accommodate this movement by providing piping flexibility through bends, expansion loops, or expansion joints. The required amount of expansion must be determined by calculating the stress level in the pipe and ensuring that it is less than the allowable stress.

(3) **Anchors and Supports.** An almost infinite variety of anchors, hangers, and supports may be seen in central boiler plants. A variety of hanger types has been standardized by the Manufacturers Standardization Society (MSS), and some of these are illustrated in figure 2-120. Custom-designed supports using structural steel shapes and standard hardware are also common.

f. Valves. Valves are available in a wide variety of types, materials, and pressure/temperature ratings to correspond to the system in which they are used and their purpose in that system. Some types of specialized valves are discussed elsewhere in the manual (Gage Cocks, paragraph 2-10; Safety Valves, paragraph 2-13; Boiler Outlet Valves, paragraph 2-14; Blowoff Valves, paragraph 2-15; Control Valves, paragraph 2-25). Several additional common types are discussed below. Specific applications should be discussed with the manufacturers representative to ensure the correct body and internal materials, seat design, packing design and material, and other details.

(1) **Function.** Valves can serve many different functions in a piping system. Broad categories of valve function include: Isolation (on-off); Throttling (control); Backflow Prevention; Pressure Relief; and Regulation.

(2) **Gate Valves.** The gate valve is the simplest in design and operation and is commonly used in boiler plants. Gate valves are used where minimum pressure dropo is important. They are employed where the valve will operate in a wide-open or fully closed position and is to be operated infrequently. Gate valves are not designed for throttling operation, and under prolonged use in a partially open position damage to the seat or disc may occur. A solid wedge type of gate valve is illustrated in figure 2-121.

(3) **Globe Valves.** The globe valve is used primarily for throttling or positioning to create a definite pressure drop. Globe valves are available in the common partial globe and seat contact type, the small needle type, and numerous variations such as top-guided, post-guided, angle, Y pattern, fluted, and cage-guided. Because of their inherent ability to exhibit repeatable flow curves, they are the most commonly used type of valve for control valve application. Globe valves can also be used in on-off service where pressure dropo in the fully open position is not of primary importance. Normally, globe valves are installed with the flow under the disc, but in certain cases where it is desirable to have line pressure assist in maintaining seat closure, flow may be directed over the disc. In motor- and air-actuated valves, this flow direction is very important in sizing the actuator. A standard single port globe valve is illustrated in figure 2-122.

(4) **Plug Valves.** The plug valve is a refinement of the earliest known valve, the spigot. Basically, it is a 90-degree rotation from open to closed position of a tapered inner valve. The downward thrust of the plug taper exerts a oompression load on the side wall, thus ensuring a continuous circumferential sealing surface. Like the gate valve, it is used primarily in on-off service only. The plug valve has the added benefit of bubbletight sealing, thus making it ideal for gaseous service. In addition, because of its large unobstructed flow passage, the plug valve is ideally suited for sluffy service. A typical plug valve is illustrated in figure 2-123.

(5) **Butterfly Valves.** Butterfly valves have been used in industry for decades, performing well-defined tasks in which they show distinct advantages over other valve types. Some butterfly valve designs can provide dependable bubbletight shutoff, and others are ideally suited for throttling or control applications, having an equal

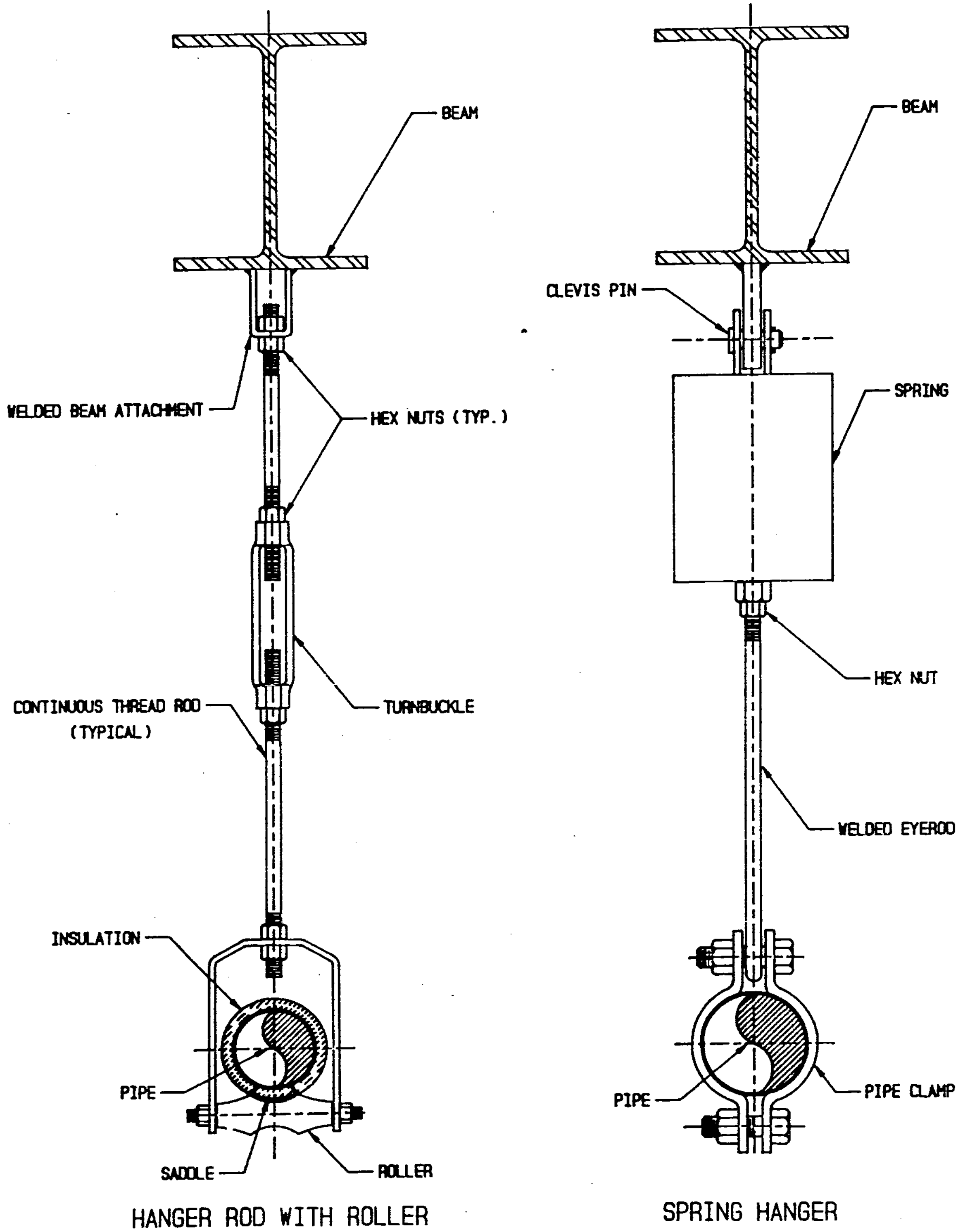

FIGURE 2-120. STANDARD HANGER TYPES FOR PIPING SYSTEMS

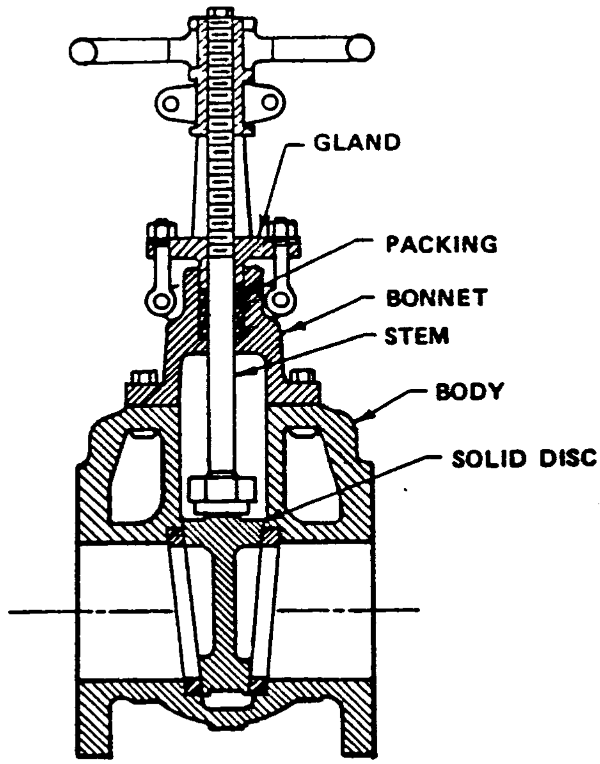

FIGURE 2-121. SOLID WEDGE DISC GATE VALVE

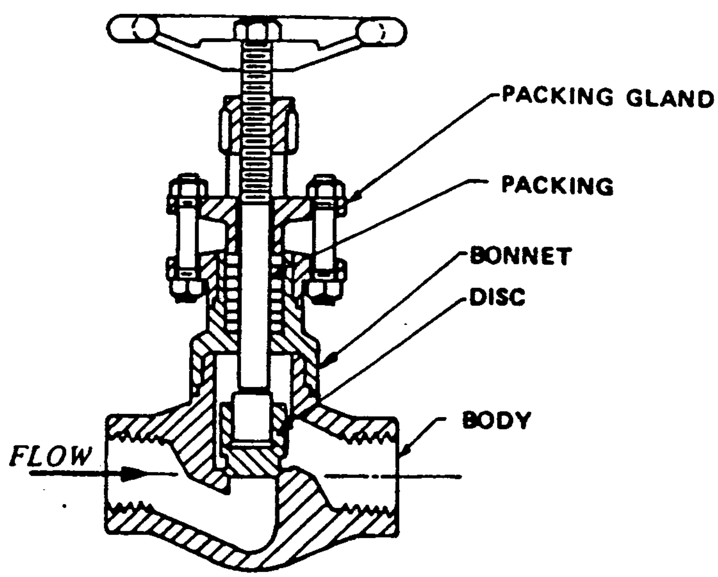

FIGURE 2-122. SINGLE PORT GLOBE VALVE

percentage flow characteristic. Butterfly valves are quick opening and highly efficient, can be operated manually or automatically, and can be used in handling a variety of media, including liquids, solids, slurries, gases, and vapor (steam). Figure 2-124 illustrates a typical butterfly valve.

(6) **Check Valves.** Check valves are designed for use in a piping system where protection against the reversal of fluid flow is desired. During operation, liquid or gas pressure will move the disc off the valve seat and allow fluid to flow through the valve with minimum pressure drop. If the fluid flow ceases or reverses direction, the reverse fluid flow and design of the disc assembly will force the disc against the seat to prevent fluid backflow. The disc weight, seat configuration, and internal spring assistance (if provided) all contribute to the ease with which the disc opens or closes and to a leaktight seal when in the closed position. Check valves can be obtained in a wide variety of styles to fit specific applications. Two of the more common types (swing check and spring loaded lift check) are illustrated in figure 2-125. g. Insulation. Insulation is used to reduce dheat loss from hot piping, eliminate condensation, reduce heat gain on cold piping, and provide personnel protection. Insulation types typically used in central boiler plant piping systems include fiberglass, mineral wool, and calcium silicate. Jacketing or vapor barrier is usually incorporated over the insulation to protect the insulation material. Common jacket materials include aluminum, fiberglass cloth, and various other fabrics.

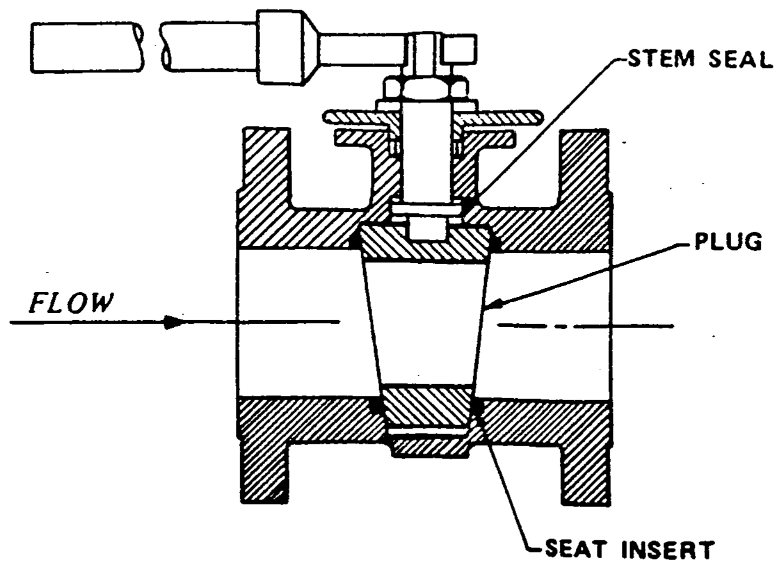

FIGURE 2-123. NON-LUBRICATED PLUG VALVE

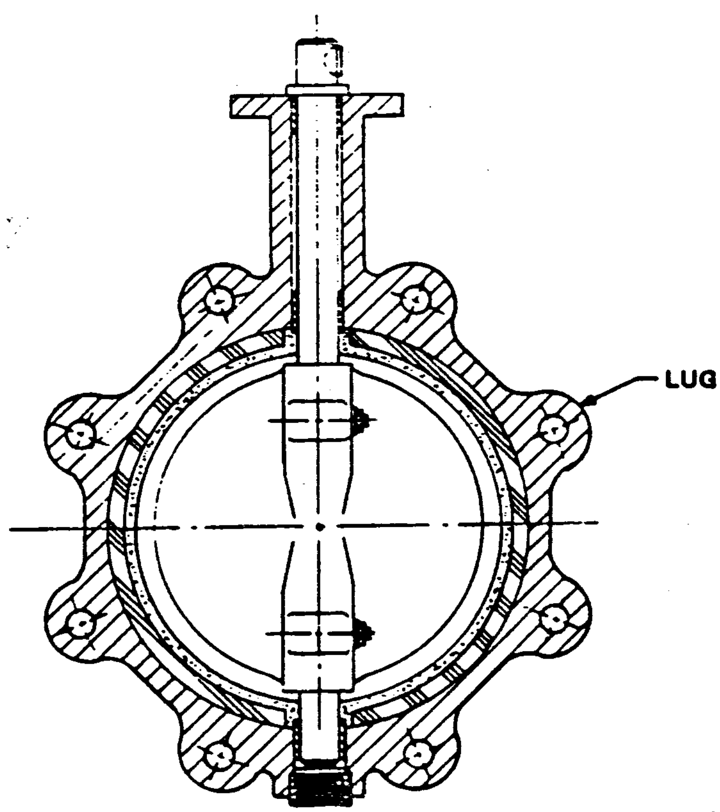

FIGURE 2-124. BUTTERFLY VALVE

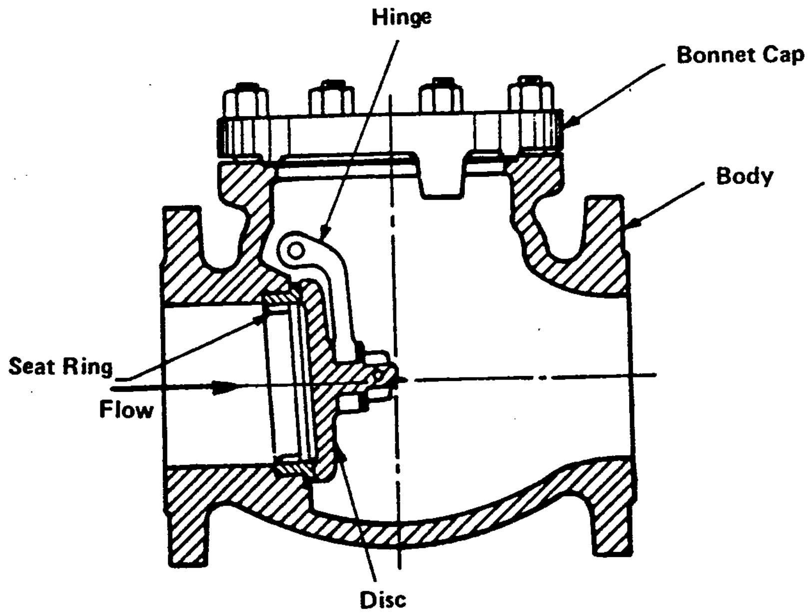

FIGURE 2-125A. SWING CHECK VALVE

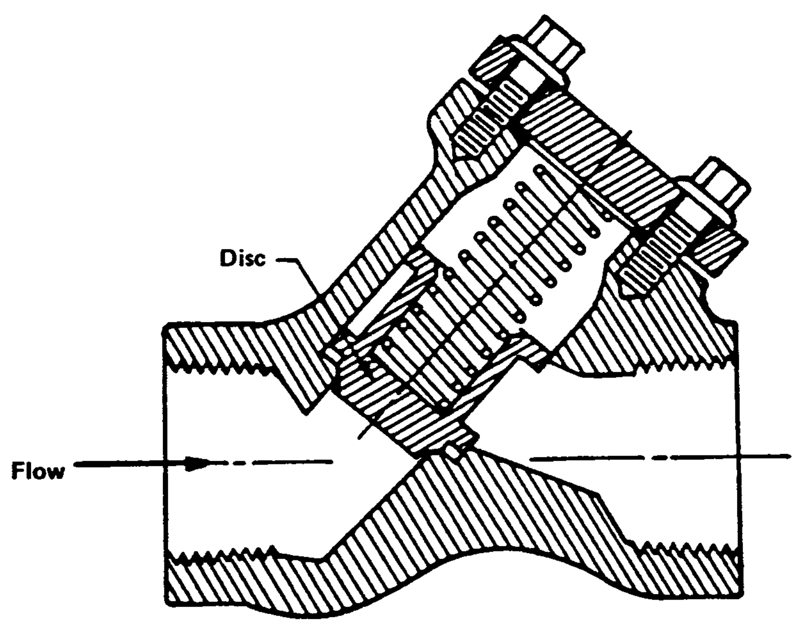

FIGURE 2-125B. Y TYPE SPRING LIFT CHECK VALVE